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REACTIVE EFFORT AS A FACTOR THAT SHAPES SIGN LANGUAGE LEXICONS

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Many properties of languages, including sign languages, are not uniformly distributed among items in the lexicon. Some of this nonuniformity can be accounted for by appeal to articulatory ease, with easier articulations being overrepresented in the lexicon in comparison to more difficult articulations. The literature on ease of articulation deals only with the active effort internal to the articulation itself. We note the existence of a previously unstudied aspect of articulatory ease, which we call REACTIVE EFFORT: the effort of resisting incidental movement that has been induced by an articulation elsewhere in the body. For example, reactive effort is needed to resist incidental twisting and rocking of the torso induced by path movement of the manual articulators in sign languages. We argue that, as part of a general linguistic drive to reduce articulatory effort, reactive effort should have a significant effect on the relative frequency in the lexicon of certain types of path movements. We support this argument with evidence from Italian Sign Language, Sri Lankan Sign Language, and Al-Sayyid Bedouin Sign Language, evidence that cannot be explained solely by appeal to constraints on bimanual coordination. As the first exploration of the linguistic role of reactive effort, this work contributes not only to the developing field of sign language phonetics, but also to our understanding of phonetics in general, adding to a growing body of functionalist literature showing that some linguistic patterns emerge from more fundamental factors of the physical world.*

Keywords: sign languages, phonetics, ease of articulation, lexical frequency, emergent patterns

1. INTRODUCTION. In sign languages, articulatory properties do not occur at the same frequency among signs in the lexicon; that is, they are not uniformly distributed (Brentari 1998, Sandler & Lillo-Martin 2006; see also Ann 2005, 2006 for nonuniformity of the distribution of handshape in Taiwanese Sign Language; Eccarius 2008, 2011 for handshape in American Sign Language (ASL), Swiss-German Sign Language, and Hong Kong Sign Language; Battison 1978 and Napoli & Wu 2003 for movement and handshape in ASL; Napoli et al. 2011 for movement in multiple sign languages; Wilbur 1987, 1990 for syllabicity in ASL; and Uyechi 1996 [1994] for location in ASL). Nonuniformity of articulatory properties among signs is unsurprising, since many other linguistic phenomena in the lexicon also follow nonuniform distributions (see Pierrehumbert 1994, Frisch 1996, Martin 2007, and Kaplan 2013 for examples and further references). The nonuniformity of the distribution of linguistic elements may be arbitrary (this is the null hypothesis), or there may be some factor (articulatory ease, perceptual salience, ease of acquisition, culture, iconicity, etc.) that favors certain classes of linguistic elements over others, so that the favored (i.e. unmarked) elements occur more frequently than the disfavored (marked) elements.

* We thank ZL Zhou for his help with preliminary data organization; Elena Radutzky for clarification of some of the signs in Italian Sign Language; Adam Stone for clarification of some of the signs in Sri Lankan Sign Language; Carol Padden and Wendy Sandler for clarification of a sign in Al-Sayyid Bedouin Sign Language; Gabriel Rivera for discussion of biomechanics; Frank Moscatelli and Craig Wiegert for discussion of physics; audiences at Dartmouth College, the University of Georgia, Swarthmore College, Universidade Federal de Santa Catarina, Universitat Pompeu Fabra, Institut für Deutsche Gebärdensprache at Universität Hamburg, Università Ca' Foscari Venezia, and the University of California at Berkeley for their feedback on portions of this work; and Karen Emmorey, Stanley Dubinsky, and three anonymous referees for their valuable suggestions. The implementation of the help we have received is solely our responsibility. We are also indebted to Bill Vicars (http://www.lifeprint.com/) and the web dictionary Signing Savvy (https://www.signingsavvy.com/) for allowing us kind usage of many images.

Following similar functionalist proposals for the nonuniform distribution of handshape (such as Ann 2005, 2006), we propose that the nonuniform distribution of certain types of path movement in the lexicon is also not arbitrary, but rather is significantly influenced by a fundamental drive toward ease of articulation, with certain path movements being more or less marked than others based on the amount of overall effort they require. We follow Napoli and colleagues (2014:425ff.) in defining articulatory effort as the total biomechanical effort (i.e. the sum of all articulatory forces), including both that involved in movement and that involved in isometric tension, and perhaps also including the cognitive costs of computation and precision, as discussed in Kirchner 1998 and 2004. We make a novel distinction between active effort and reactive effort, where active effort (the usual subject of study in work on ease of articulation) is the effort of moving an articulator or holding it stable, and reactive effort is the effort expended elsewhere in the body to resist incidental movement induced by active articulation.[1] Reactive effort has not previously received attention in the linguistics literature, although it is a concern in other fields. For example, it is presumed in literature on dance (e.g. Phillips 2005) and athletics (e.g. Debu et al. 1989, Willardson 2007) concerning muscle strength in stability training.

We demonstrate that the nonuniform distribution of certain types of path movements in the lexicon correlates with reduction of reactive effort by examining the lexicons of the dialect of Italian Sign Language (*lingua dei segni italiana*, henceforth LIS) used in the Sicilian province of Catania; Sri Lankan Sign Language (SLSL); and Al-Sayyid Bedouin Sign Language (ABSL), a village sign language used in the Southern District of Israel. Our main results are that the drive to reduce reactive effort is responsible for the fact that signs that do not affect torso stability are statistically overrepresented in the lexicon, while signs that destabilize the torso are statistically underrepresented, with those that destabilize the torso via twisting being less common than those that destabilize the torso via left-right or front-back rocking.

We begin in §2 by introducing the notion of reactive effort. We then discuss how ease of articulation with respect to reactive effort in sign languages is manifested by resisting incidental torso movement, and we make predictions about which types of movements are expected to be more or less preferred. In §3, we describe our methods for collecting data from LIS, ABSL, and SLSL to test these predictions. We then discuss in §§4–5 various ways in which these data demonstrate that reduction of reactive effort can shape the lexicon by influencing the relative frequency of certain kinds of path movements, and we briefly explore the secondary effect of moving the center of mass in §6. We conclude in §7 that the notion of reactive effort we have introduced here must be considered in sign language phonetics in order to adequately account for certain issues in the shape of the lexicon and that it may play a role in other areas where articulatory ease is important, including in spoken languages.

2. Reactive effort and torso movement. In this section, we define reactive effort and discuss the biological and linguistic reasons why extraneous torso movement is undesirable and, thus, why reactive effort is called upon to resist it when it is induced. From this, we make predictions about the relative frequency of certain manual articulations in the lexicon based on how much reactive effort is needed to resist the corresponding torso movements they induce.

[1] For brevity, we say that an articulation 'induces' some type of movement in a body part to mean that the articulation creates forces that act upon that body part in such a way that it will undergo the specified movement if there is not enough resistance to the created forces.

2.1. Reactive effort. Because of the segmented nature of the spinal column, the torso can move in different ways. However, modeling each of the twenty-four presacral vertebrae (i.e. the unfused vertebrae above the sacrum and coccyx) would be more complex than needed for this initial study, so we focus on movement of the torso as a whole, ignoring the individual movements of the vertebrae. Ultimately, this simplification does not affect our general results, because we are concerned only with large-scale differences between fundamentally different types of torso movement (twisting versus rocking), not with fine-grained differences between similar types of torso movement (e.g. rocking versus arched bending).

Movement of the entire torso is typically articulated with active effort by activating muscles such as the oblique abdominals and the erector spinae to directly push and pull the torso in various directions. However, the torso can also be induced to move without using these muscles by actively articulating some other body part instead. For example, vigorously waving a hand in the air can induce left-right rocking of the torso without having to use muscles in the torso itself; only muscles within the arm are needed. This incidental rocking can be resisted, however, by using the torso muscles to isometrically hold the torso in place. We define reactive effort as any such isometric resistance to movement of a body part externally induced by movement of a different body part; this contrasts with active effort, which is the effort expended within a body part itself to move or stabilize it.

Studies on ease of articulation in language have previously focused only on active effort (see e.g. Kirchner 1998, 2004); we have found no work in linguistics that analyzes, or even mentions, reactive effort. This is expected, because phonetics research has historically been concerned with spoken languages, and the masses of the oral articulators are so small that no one has yet noticed significant effects elsewhere in the body. Strongly opening and closing the jaw to gnash the teeth is perhaps the most forceful movement the oral articulators can make, but that barely induces incidental head movement. Furthermore, such strong jaw movement is well outside the norm for ordinary spoken languages; speech is overwhelmingly made up of articulations that move smaller masses with less force: lip rounding, velum lowering, tongue curling, and so forth.

In contrast, sign languages regularly make use of path movement (articulation involving the elbow and/or the shoulder, also known as primary movement), which causes the forearm or entire arm to move so that the hand traces a route through space, known as the path (van der Hulst 1993, Brentari 1998, van der Kooij 2002). Unlike the oral articulators, the forearm and whole arm are massive enough to induce easily observable incidental movement elsewhere in the body, specifically in the torso. As we discuss in §2.2, torso movement is generally undesirable, so humans resist it by expending reactive effort. Sign languages thus provide an opportunity to broaden our knowledge of the drive for articulatory ease in language in a way that spoken languages thus far have not.

2.2. Avoidance of torso movement. The torso plays a special role in the biology and social behavior of humans, including in language. For a variety of reasons, humans generally prefer to maintain an upright, forward-facing orientation of the torso, and we will expend reactive effort to do so. Evidence for this preference can be seen in the evolutionary development of bipedal locomotion from quadrupedal locomotion. Most obviously, we have evolved an upright, forward-facing posture that allows us to look where we are going. However, bipedal locomotion induces twisting of the torso, which has a destabilizing effect if not resisted. In evolving bipedalism, the human skeleton underwent changes, such as extended hips and legs (McHenry 1992), that allowed bipedal locomotion to take less biomechanical energy than quadrupedal locomotion (Sockol et al. 2007). A longer leg requires large, powerful muscles to initiate and stop its swing (Robinson et al. 1972), and movement of the legs' larger mass for walking induces twisting of the torso, which we resist by swinging the arms (Witte et al. 1991) and with the reactive effort of activating the gluteus maximus and other muscles (Lovejoy 1988). Notably, humans evolved a particularly robust iliopsoas muscle (a compound muscle that stretches from the lower spine to the femur) to resist twisting while walking, unlike our fellow great apes, who have a smaller and weaker iliopsoas muscle (Kimura 2002) and need to rock sideways instead to stabilize themselves when moving bipedally (Michele 1962, Robinson et al. 1972, Lovejoy 1988). Thus, the human body has evolved an innate biological resistance to torso twisting, as well as rocking, since our evolutionary development avoided the rocking strategy that the other great apes use for bipedal movement.

Another piece of evidence that humans prefer to maintain a stable torso position comes from how we use the eyes to interact with each other. A fixed torso position allows humans to keep each other's eyes easily visible in order to use them to deliver and receive information (Kobayashi & Kohshima 2001), such as indicating fear by showing larger sclera (the portion of the eye surrounding the iris) area (Morris et al. 2002, Whalen et al. 2004, Smith et al. 2005) and indicating potential threats by aiming the eye gaze (Kawashima et al. 1999, Hooker et al. 2003). In addition to these primal tasks, the eyes are also used to convey information in sign languages: when a signer uses indexicals (including in agreement processes) or a classifier predicate, the signer's gaze will typically move to at least one of the indexed locations or follow the classifier predicate (Thompson et al. 2006), and the addressee's gaze will follow the signer's gaze (Emmorey et al. 2009). For most other parts of the conversation, however, the conversants' eyes are on each other's faces. If there are multiple participants, the signer's eyes move across the faces of the various addressees, where the signer's gaze can invite others to join in the conversation (Mather 1987).

Tomasello and colleagues call this human potential for eye-based information exchange the 'cooperative eye hypothesis' (2007:314), which they tested in a study of chimpanzees, gorillas, bonobos, and human infants. The human infants' gaze followed the direction of the adults' eyes, but for the other great apes, the infants' gaze followed the direction of the adults' heads. The cooperative eye hypothesis is supported by the anatomy of the human eye itself: among primates, humans have the largest sclera and the only white sclera (Kobayashi & Kohshima 1997:767–68). These special evolutionary developments make it much easier for us to use the eyes to communicate. Consequently, we have a natural inclination to facilitate the use of the eyes for information exchange by holding the torso in a position so that we can see each other's eyes as easily as possible.

Further, we note that torso movement often has a linguistic function in sign languages. For example, leaning backward can be used to express surprise (Sze 2008), and different torso positions can be used to mark topic boundaries (Winston & Monikowski 2003) or to role shift (i.e. to take on different roles in a narrative) (Engberg-Pedersen 1993). Extraneous torso movement could thus be erroneously interpreted as meaningful by the addressee, so maintenance of a fixed torso position when meaningful torso movement is not intended seems important while signing, though we know of no relevant study addressing this issue.

Thus, there are multiple pressures that drive humans to avoid unnecessary torso movement, especially within the context of sign languages. We expect that manual articulations that might induce incidental torso movement would be resisted by reactive effort, so if there is a general linguistic drive to reduce articulatory effort, whether active or reactive, then such destabilizing manual articulations will be disfavored.

2.3. PREDICTIONS. There are two primary ways manual movement can destabilize the torso: twisting and rocking. The potential for twisting can be seen in the ASL sign ACTIVITY in Figure 1, in which the hands move together to the right and together to the left, crossing the midsagittal plane, which causes the torso to rotate about the craniocaudal axis (the vertical axis through the center of the head and torso) if not resisted by reactive effort. (All ASL data reproduced here are annotated video stills taken from the online dictionary Signing Savvy 2014; we use subscripts to distinguish different signs listed under the same English word, with the subscript corresponding to the order of appearance in Signing Savvy.)

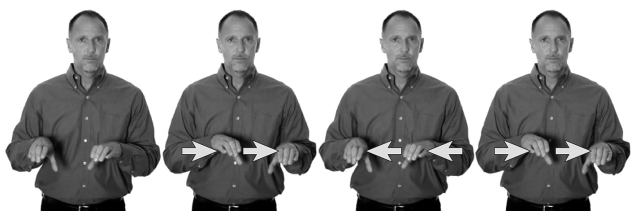

FIGURE 1. Potential twisting induced by ACTIVITY in ASL.

The potential for rocking can be seen in the ASL sign MAYBE in Figure 2, in which the hands move up and down in alternation: when the right arm moves up, the left arm moves down. This causes the torso to rock left and right (i.e. to rotate about the sagittal axis through the front and back of the lower torso) if not resisted by reactive effort.

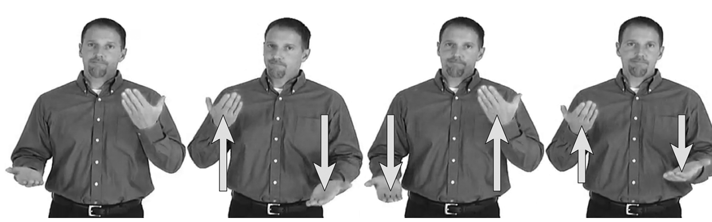

FIGURE 2. Potential left-right rocking induced by MAYBE in ASL.

Rocking can also be induced in the front-back direction, as in the ASL sign TEACH in Figure 3, in which the hands move together away from and toward the head. This causes the torso to rock forward and backward (i.e. to rotate about the transverse axis through the sides of the lower torso) if not resisted by reactive effort.

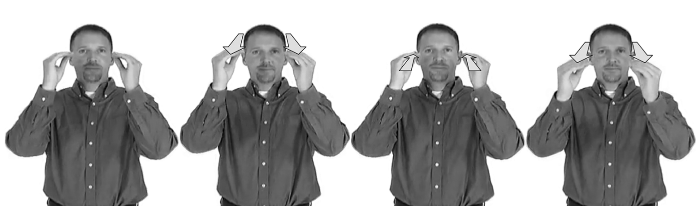

FIGURE 3. Potential front-back rocking induced by TEACH in ASL.

There are many ways to explore how reactive effort is used to maintain torso stability in sign languages. Since this area of research has not been studied before, in this initial investigation, we consider only the most fundamental aspects. In §4, we look first at whether a sign induces any kind of torso movement at all, that is, whether it is destabilizing (inducing some type of torso movement) or stable (inducing no torso movement). For the destabilizing signs, we further distinguish in §5 between those that induce twisting (as in Fig. 1) and those that induce rocking (as in Figs. 2 and 3), since these are the two distinct ways that the entire torso can rotate when it is approximated as a cylinder. Finally, we note briefly in §6 that there also appears to be a secondary preference for movements that do not change the center of mass. We do not consider other factors that also could affect reactive effort, such as the speed of the manual movement or the distance of the hands from the torso, though these factors warrant future study.

We restrict our analysis to just those signs with FREE TWO-HANDED PATH MOVEMENT, the characteristic movement of type 1 signs in Battison's (1978) classic typology of signs. These are signs in which both of the manual articulators trace their own paths without continuous contact. We restrict our analysis to these signs for two reasons. First, signs that are not free, in which the manual articulations touch continuously, are bound by constraints on movement that signs with free movement are not bound by. Consider the ASL sign AMERICA in Figure 4, in which the fingers remain interleaved throughout the entire duration of the sign.

FIGURE 4. Connected manual articulators in AMERICA in ASL.

Because the manual articulators cannot be separated in such connected movement, it is impossible for them to induce rocking in the same way that MAYBE does (Fig. 2). Signs with free movement, however, can move the articulators in any direction, together or in alternation, so they do not have the same inherent restriction to a subset of the total range of bimanual movement.

Second, two-handed path movement involves the greatest amount of moving mass. When two manual articulators are tracing a path, there is twice as much mass being moved as when only one manual articulator traces the same path. In addition, path movement involves one or both of the two most proximal joints in the manual articulators, while local movement involves only some combination of the most distal joints (the radioulnar, wrist, base knuckles, and/or interphalangeal). The proximal joints move a much larger mass than the distal joints do (Napoli et al. 2014:431ff.), so path movement requires greater articulatory effort. This makes them the most likely signs to be targeted by the fundamental drive to reduce articulatory effort, because there is more overall articulatory effort at stake. Almost all signs with two-handed path movement in our data are reflexively symmetrical; that is, they are mirror images of each other across a plane (typically the midsagittal plane, but sometimes a transverse or vertical plane). This finding matches that of Napoli and Wu (2003) and conforms to a general motor preference for reflexive symmetry when both hands move (Kelso 1984, Semjen et al. 1995).

Because path movement occurs in three-dimensional space, we can define three perpendicular axes to describe the possible directions in which the hands may move. We choose the system of cardinal axes in Figure 5: the away-toward axis or AT-axis (also known as the sagittal, medial, or anteroposterior axis) points in the direction of the front and back of the signer; the left-right or LR-axis (the transverse, frontal, or mediolateral axis) points in the direction of the sides of the signer; and the up-down or UD-axis (the vertical, longitudinal, or craniocaudal axis) points in the direction of the head and feet of the signer.

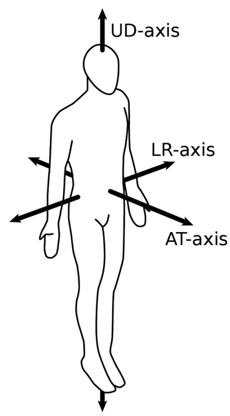

FIGURE 5. Cardinal axes for describing manual movement.

In this work, when we describe movement with respect to these axes, we say that the manual articulators move along the relevant axes, which means they move parallel to the axes, though not necessarily directly on them. For example, in the ASL sign MAYBE (Fig. 2), we describe the movement as being along the UD-axis, because the hands are moving up and down, parallel to the UD-axis.

Given the existence of a fundamental drive for reducing articulatory effort, and given our proposal that reactive effort is a type of articulatory effort that needs to be taken into consideration, we predict that among those signs already using the greatest active effort (i.e. those with two-handed path movement), we should see the effects of the reduction of reactive effort. This means that signs with destabilizing manual movement should be dispreferred in some way, because they induce twisting or rocking of the torso and thus require the signer to expend reactive effort in order to prevent this undesirable extraneous torso movement. In addition, we show in §5 that twisting of the torso requires more reactive effort to resist than rocking does, so we further predict that twisting should be dispreferred among destabilizing signs. There are many ways in which these biases could be realized in a sign language (historical change, conversational frequency, register differences, order of acquisition, etc.). We chose to look at their relative frequency among signs in the lexicon.

3. DATA COLLECTION AND CODING. In this section, we describe our methodology for collecting and analyzing data in order to test the predictions in §2.3 concerning the distribution of certain types of movement in a sign language's lexicon.

The three languages analyzed in this study (LIS, SLSL, and ABSL) were selected because they are genetically unrelated to each other, their signs are available in accessible print versions for ease of data analysis, and they cut across the age and stability factors often pointed to for characterizing sign languages (as in Aronoff et al. 2008): LIS is a national language that dates back at least to Tommaso Silvestri's founding of the first Italian school for the deaf in 1784 in Rome (Radutzky 2001:14); SLSL is a national language that dates back at least to the founding of the Deaf and Blind School in 1912 in Ratmalana (Sri Lanka Central Federation of the Deaf 2007:viii); and ABSL is a village sign language that emerged in southern Israel in the 1930s (Meir et al. 2012:xv). Nothing about the linguistic structure of these three languages informed our decision to analyze them; indeed, we had not previously examined SLSL and ABSL before undertaking this research. Since nothing phonetically unites these three languages as a group, we expect them to be crosslinguistically representative.

For LIS, we had access to two print dictionaries, plus a video companion version of one of them, all in a language (Italian) we are familiar with. The more comprehensive of the dictionaries, *Dizionario bilingue elementare della lingua dei segni italiana LIS* (Radutzky 2001), draws signs from more than one variety of LIS, while the other, *Dizionario dei segni* (Romeo 1991), presents signs used in the Sicilian province of Catania, but which were chosen because they are recognized and often used in other parts of Italy. Because of its sufficiently large size (about 1,400 total signs) and focus on a single variety of LIS, we selected Romeo 1991 as the primary source of our data set of LIS signs.

For SLSL, we had access to two dictionaries: an online copy of a print dictionary and phrasebook, *An introduction to Sri Lankan Sign Language* (Stone 2007), and a print dictionary, *Sri Lanka Sign dictionary* (Sri Lanka Central Federation of the Deaf 2007, henceforth SLCFD 2007). Stone 2007 is written in both Sinhala and English, and it covers the variety of SLSL used in and around the Rohana Special School in Matara, Sri Lanka. However, of the two dictionaries, Stone 2007 is smaller (about 560 signs and phrases) and has a narrower semantic focus, so we chose to work with the larger and more comprehensive SLCFD 2007, which has about 1,240 signs from standard Sri Lankan Sign Language. It is written in Sinhala, Tamil, and English.

For ABSL, we had access to *Al-Sayyid Bedouin Sign Language dictionary* (Meir et al. 2012), a relatively small work with only about 280 signs and the sole print dictionary that we know of for ABSL, written in Arabic, Hebrew, and English. Raising awareness of understudied languages is an important goal for us, and since our sources for LIS and SLSL are sufficiently robust, we felt comfortable working with a smaller data set for ABSL in order to showcase it in this work.

To form our data set for each language, we extracted every example of a sign with free two-handed path movement, excluding signs for numbers and certain polysyllabic signs. Numbers were excluded because there could be an arbitrary number of them listed in the dictionary, depending on how comprehensive it is (e.g. Romeo 1991 contains ninety-four distinct signs for numbers in LIS, while SLCFD 2007 contains eighty-four distinct signs for numbers in SLSL), which could bias our data toward the properties found in signs for numbers. This exclusion, however, had little to no effect on our findings, since numbers tend not to have two-handed path movements, instead having unusual or highly marked local articulations not characteristic of the language as a whole (Eccarius 2008).

Among polysyllabic signs (signs with more than one path; see Wilbur 1990), we included only those that retrace the same path backward due to 180° rotation of the direction of movement, as in the ASL signs ACTIVITY, MAYBE, and TEACH in Figs. 1–3, and those that retrace the same circular or elliptical path forward, as in the ASL sign PACK in Figure 6.

FIGURE 6. Polysyllabic circular movement in PACK in ASL.

All other polysyllabic signs were excluded, because it is not clear how each of the different paths (or the transitions between them) should count in the overall tally in comparison to signs with a single (potentially retraced or repeated) path. For example, the ASL sign BOX in Figure 7 begins with a downward path movement in the first syllable, followed by a transition in which the hands move up and then out to the sides to be in position for articulating the second syllable, which has a second downward path movement.

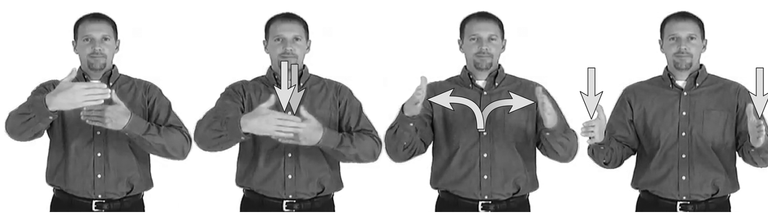

FIGURE 7. Polysyllabic BOX with multiple different paths in ASL.

Among these excluded polysyllabic signs were compounds and phrases. Excluding such signs is desirable: if any of the individual components of a compound or phrase is already in the data set (either alone or as part of another compound or phrase), counting the compound or phrase would count the component signs multiple times, which would bias the data in favor of those signs that are prone to being used in compounds and phrases.

We worked together to code the signs in the resulting data sets, based on the type of path movement: whether the hands move in the same (+) or opposite (−) directions along each of the three cardinal axes (AT, LR, and UD). For example, if the hands move along the UD-axis in the opposite direction (as in the ASL sign ALLIGATOR in Figure 8), then the sign was coded as −UD.

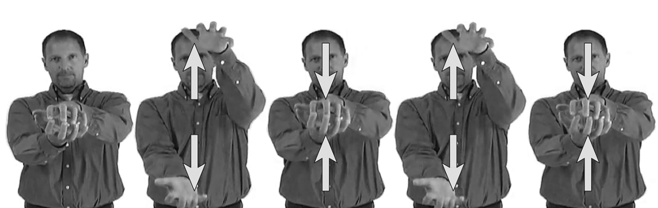

FIGURE 8. −UD movement in ALLIGATOR in ASL.

Similarly, if the hands move along the LR-axis in the same direction (as in the ASL sign ACTIVITY in Fig. 1), then the sign was coded as +LR. If the hands do not move along a given axis at all, they were coded as 0 for that axis.

Note that the hands can move along multiple axes at the same time, as in the ASL sign PACK in Fig. 6, in which the hands move in opposite directions along the UD-axis (−UD) and in the same direction along the LR-axis (+LR); since the hands do not move along the AT-axis, PACK is coded as 0 for AT movement. And in the ASL sign SPANISH in Figure 9, the hands move in the same direction along the AT-axis (+AT), the same direction along the UD-axis (+UD), and opposite directions along the LR-axis (−LR).

FIGURE 9. +AT +UD −LR movement in SPANISH in ASL.

Coding only signs with free two-handed single or retraced path movement was usually straightforward, but for a few signs in all three languages, the movement depicted in the dictionary was vague enough that we could not agree, or in some cases, we suspected that there was an error in the depiction. For the questionable signs in LIS, we first turned to Radutzky's printed and video dictionaries, and if those did not resolve the issue to our satisfaction, we asked Elena Radutzky directly, and she was gracious enough to answer in detail. For the questionable signs in SLSL, we similarly consulted Stone 2007 first, and then if needed, we sought further clarification from Adam Stone, who was also gracious with his help, as were Carol Padden and Wendy Sandler, who we turned to for clarification about the one questionable sign in ABSL.

Next, we divided the signs for analysis by whether they are monoaxial (having path movement along a single cardinal axis) or multiaxial (having path movement along two or three cardinal axes), because multiaxial movement is more complex and thus subject to additional cognitive constraints on motor coordination that may potentially skew the data differently from the monoaxial data. For example, when tracing two parallel circles reflected across and drawn on the midsagittal plane, it is relatively easy for the hands to trace those circles in the same direction, either clockwise or counterclockwise, as viewed from the right, whether the hands are moving in phase with each other (as in the ASL sign ROWING in Figure 10) or out of phase (as in the ASL sign BICYCLE in Figure 11).

FIGURE 10. In-phase (+AT +UD 0LR) circular path in ROWING in ASL.

FIGURE 11. Out-of-phase (−AT −UD 0LR) circular path in BICYCLE in ASL.

However, tracing these circles with one hand moving clockwise and the other counterclockwise, so that movements in the AT and UD directions have opposite polarity, is a more difficult task. Thus, closed paths with opposite values of AT and UD should be rarer than would otherwise be expected, based solely on the biomechanics of the manual articulations. This dependency between the AT and UD axes is not present for monoaxial paths, so we expect a purer biomechanical outcome for signs with monoaxial paths.

Note that while signs with curved paths are necessarily multiaxial, not all multiaxial signs have a curved path. For example, the ASL sign TRIANGLE$_2$ 'three-sided geometric figure' in Figure 12 has straight multiaxial (0AT +UD −LR) movement.

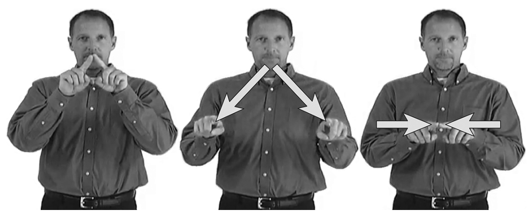

Figure 12. Straight multiaxial movement in TRIANGLE$_2$ in ASL.

The final counts from Romeo 1991 (for LIS), SLCFD 2007 (for SLSL), and Meir et al. 2012 (for ABSL) for all of the monoaxial and multiaxial signs with free two-handed single or retraced path movement are given in Table 1.

	LIS	SLSL	ABSL
monoaxial	107	35	15
multiaxial	185	31	18
total	292	66	33

Table 1. Number of signs with free two-handed single or retraced path movement.

These signs are further broken down by their specific axial movement type in Tables 2 (monoaxial) and 3 (multiaxial). Note that there are twenty-seven total ways that the three values +, −, and 0 can be assigned to the three cardinal axes; six of these are monoaxial, and one has no movement at all, leaving twenty possible multiaxial combinations.

	LIS	SLSL	ABSL
+AT	12	2	1
−AT	5	4	0
+UD	30	10	7
−UD	17	4	3
+LR	1	0	0
−LR	42	15	4

Table 2. Distribution of monoaxial signs by axial movement.

There is no statistically significant difference between the three languages' distributions of the six types of monoaxial signs (p = 0.73 for Fisher's exact test for homogeneity using the fisher.test() function in the R programming language (R Core Team 2015)) or of the twenty types of multiaxial signs (p = 0.51 using a simulated p-value with 100,000 replicates). That is, there is insufficient evidence to conclude that monoaxial or multiaxial signs in any of the three languages follow a different underlying distribution from what the other languages follow.

4. Analysis of stable versus destabilizing movement. In this section, we compare the relative frequency of stable versus destabilizing signs in LIS, SLSL, and ABSL, looking first at monoaxial signs and then at multiaxial signs.

AT	UD	LR	LIS	SLSL	ABSL
+	+	+	4	0	0
+	+	0	38	5	2
+	+	−	13	5	1
+	0	+	5	2	0
+	0	−	34	3	2
+	−	+	0	0	0
+	−	0	0	0	0
+	−	−	0	0	0
0	+	+	5	0	1
0	+	−	51	9	6
0	−	+	1	1	2
0	−	−	1	0	0
−	+	+	0	0	0
−	+	0	0	0	0
−	+	−	0	0	0
−	0	+	1	0	0
−	0	−	4	1	0
−	−	+	3	0	0
−	−	0	25	5	4
−	−	−	0	0	0

Table 3. Distribution of multiaxial signs by axial movement.

4.1. Stability in monoaxial signs. For monoaxial signs, we classify +UD and −LR movements as stable, because they induce no torso movement, while +AT, −AT, −UD, and +LR movements are classified as destabilizing, because they induce some type of torso movement. Thus, if reduction of reactive effort plays a role in determining which kinds of signs are more or less preferred, we expect to find a disproportionate amount of stable movements in comparison to destabilizing movements among monoaxial signs. We show in this section that this prediction holds for all three languages.

The monoaxial signs in our data for LIS, SLSL, and ABSL are distributed between stable movements (+UD and −LR) and destabilizing movements (+AT, −AT, −UD, and +LR) as shown in Table 4. These distributions are also graphed proportionally in Figure 13.

	LIS	SLSL	ABSL
stable	72	25	11
destabilizing	35	10	4

Table 4. Distribution of monoaxial signs by stability.

If there were no reason for any monoaxial movement to be favored over any other, we would expect a language's monoaxial signs to be uniformly distributed among the six monoaxial movements, so that about one-third of the monoaxial signs in a language would be stable (since two of the six possible monoaxial movements are stable) and about two-thirds would be destabilizing (since four of the six possible monoaxial movements are destabilizing). This expected uniform distribution is graphed as a proportion to the right of the observed proportions from the three languages in Figure 13.

The observed distributions of monoaxial signs in LIS, SLSL, and ABSL by stability are consistent with each other ($p = 0.86$ for Fisher's exact test), but they are not consistent with the expected uniform distribution: the stable signs are overrepresented, while the destabilizing signs are underrepresented ($p < 0.01$ for each of the three languages for Pearson's χ^2 test for goodness of fit using the chisq.test() function in R). Therefore, some other factor must be shaping the lexicon to favor stable monoaxial signs and disfavor destabilizing monoaxial signs.

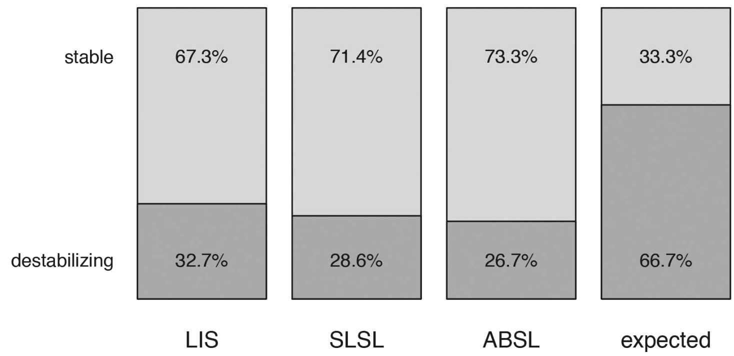

FIGURE 13. Relative proportions of monoaxial signs by stability.

We propose that a drive to reduce reactive effort is the factor responsible here: stable signs induce no torso movement and thus require no reactive effort, so they are favored and will be overrepresented, while destabilizing signs require reactive effort to resist induced torso movement, so they are disfavored and will be underrepresented. The observed distributions of stable versus destabilizing monoaxial signs in LIS, SLSL, and ABSL conform to this proposal and thus provide evidence that reduction of reactive effort is indeed a factor that has shaped their lexicons.

4.2. STABILITY IN MULTIAXIAL SIGNS. Of the twenty different combinations of axial movement that are multiaxial, there is only one that is purely stable (0AT +UD −LR, as in the ASL sign TRIANGLE$_2$ in Fig. 12), leaving nineteen multiaxial combinations with some degree of destabilizing movement. Of these nineteen destabilizing multiaxial movements, six are expected to be rare for reasons unrelated to reactive effort. For example, some multiaxial combinations pose coordination difficulties: when the hands move along both the AT- and UD-axes reflected across the midsagittal plane, we often prefer for both movements to have the same polarity, as noted in §3. That is, we prefer +AT +UD or −AT −UD (with or without movement along the LR-axis) but disprefer +AT −UD and −AT +UD. Indeed, none of the signs we looked at use any of the six possible multiaxial movements in which AT and UD have opposite polarity. Thus, we exclude such combinations from consideration for the remainder of the discussion, leaving us with thirteen multiaxial combinations with some degree of destabilizing movement.

Note that this is not merely an accounting trick. There is a genuine reason to exclude these six movements from consideration: they are dispreferred for a reason that is independent of what we are testing (which is the potential for inducing torso movement). Furthermore, leaving the six categories in would not only obfuscate the true nature of what is going on, but it would do so in our favor: these categories are empty in all three languages, and including them would make it easier to find a statistically significant difference between the observed data and a uniform distribution in the direction we expect, since they are all part of the destabilizing group of signs, which we expect to be statistically underrepresented.

The multiaxial signs in our data for LIS, SLSL, and ABSL are distributed between one stable movement (0AT +UD −LR) and thirteen destabilizing movements (all other remaining types) as shown in Table 5. These distributions are also graphed proportionally in Figure 14, along with the expected proportion according to a uniform distribution in which each of the fourteen types of multiaxial signs is equally likely.

As with the monoaxial signs, there is no significant difference between the three languages' overall distributions for multiaxial signs (p = 0.80 for Fisher's exact test), and

	LIS	SLSL	ABSL
STABLE	51	9	6
DESTABILIZING	134	22	12

TABLE 5. Distribution of multiaxial signs by stability.

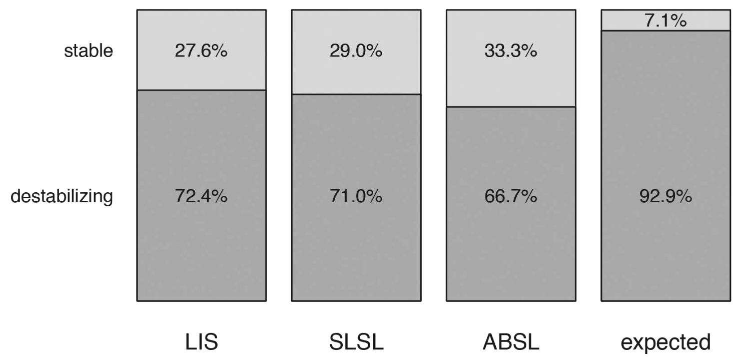

FIGURE 14. Relative proportions of multiaxial signs by stability.

the stable signs are overrepresented in each language, while the destabilizing signs are underrepresented ($p < 0.01$ for LIS and SLSL and $p = 0.01$ for ABSL for Pearson's χ^2 test, with a simulated p-value using 100,000 replicates for SLSL and ABSL due to their small sample sizes). Note that even though the destabilizing multiaxial signs outnumber the stable multiaxial signs in raw numbers, what matters is that they fall short of the expected proportion from a uniform distribution: thirteen out of fourteen types of multiaxial movement should account for approximately 92.9% of the data, but the thirteen destabilizing movements make up only about 70% of the multiaxial signs in each language. Thus, we have the same general result for multiaxial signs as we do for monoaxial signs in all three languages, providing further evidence that reactive effort is a factor in the shape of sign language lexicons, favoring stable movements and disfavoring destabilizing movements.

4.3. SUMMARY. Whether we are looking at monoaxial or multiaxial signs, destabilizing movements as a group are underrepresented in comparison to what would be expected by random chance, and stable movements as a group are overrepresented, a result that matches our predictions based on a drive to reduce reactive effort as part of the larger drive to reduce all articulatory effort. Not only that, but the extent of the difference between destabilizing and stable signs is almost identical in the three languages, supporting our expectation that these biomechanical effects are fundamental to the human body and will be realized in similar ways crosslinguistically.

Since the stable movements for monoaxial and multiaxial signs involve one or both of +UD and −LR, one might propose that the overrepresentation of stable movements could be due to concerns of muscle activation rather than torso stability, given the general preference for in-phase symmetric motion with homologous muscle activation (Swinnen et al. 1998, Kennerley et al. 2002, Li et al. 2004, Swinnen & Wenderoth 2004), which +UD and −LR both involve. However, +AT also involves in-phase symmetric motion with homologous muscle activation, but it is a destabilizing movement and is underrepresented in comparison to +UD and −LR. Thus, while muscle activation surely is a factor (witness the total absence of the six multiaxial movements in which AT and UD have opposite polarity, none of which have homologous muscle activation), an account looking only at muscle activation is inadequate in comparison to our account, which looks at reactive effort and correctly predicts not only the preference for +UD and −LR but also the dispreference for +AT.

In the next section, we discuss ways that two different kinds of destabilizing movements (twisting and rocking) can be compared to each other in order to give a more fine-grained analysis of reactive effort.

5. SUBTYPES OF DESTABILIZING MOVEMENT. Because stable movements induce no torso movement, they require no reactive effort. There may of course be differences between them in terms of active effort (e.g. extending the arms forward and lifting them up against the pull of gravity generally requires more active effort than moving them to the left or right at a constant height), but since our present concern is with reactive effort only, we set comparisons of active effort aside.

In contrast, destabilizing movements can differ in the amount of reactive effort they require, because the types and degree of torso movement they induce can differ. This is a highly complex area, and for ease of discussion, we focus on just one specific distinction among destabilizing movements: whether they induce twisting or rocking of the torso. In this section, we define this distinction in terms of the moments of inertia of the torso and explore its ramifications for the types of signs we expect to be more or less frequent in the lexicon, finding evidence from LIS, SLSL, and ABSL that this distinction between types of destabilizing movements correlates with their relative frequency in the lexicon among monoaxial signs.

5.1. MOMENTS OF INERTIA OF THE TORSO. When a force causes an object to rotate rather than move in a straight line, there is a torque. Mathematically, a torque $\boldsymbol{\tau}$ is the cross product of the relevant force vector $\mathbf{F}$ with the distance vector $\mathbf{r}$ between the object's center of mass and the location where the force is applied: $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$. Just as objects have an inherent resistance to being moved in a straight line by a force (their mass), they also have an inherent resistance to being rotated by a torque. This resistance is their moment of inertia. A single object can have multiple different moments of inertia; the particular moment of inertia of an object relevant for a given torque depends on a variety of factors, such as the distribution of mass within the object, the object's shape, and the axis that the object is rotating around.

For the purposes of this discussion, we approximate the torso as a solid, uniformly dense cylinder (Figure 15), with mass m, height h, and radius r. Such an object has two relevant moments of inertia: one for twisting around the craniocaudal axis (I_{twist}) and one for both left-right rocking and front-back rocking (I_{rock}). Note that the moments of inertia for front-back rocking and for left-right rocking are both given by I_{rock}, even though they involve rotation around different axes, because of the symmetric nature of the cylinder.

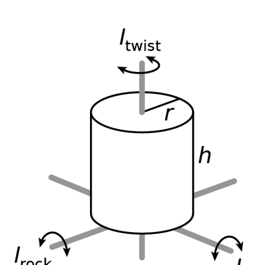

FIGURE 15. Cylindrical approximation of the torso for calculating moments of inertia for twisting versus rocking.

Since the human torso is typically wider than it is deep, an elliptical cylinder or perhaps a rectangular prism would be a more accurate model of the torso in a fuller analysis. Indeed, even more complex models could be used instead, taking into account the gradual tapering of the torso from the shoulder to the waist, the nonuniform distribution of mass within the torso, and so forth. However, such increased accuracy results in relatively small differences between the relevant moments of inertia in comparison to the difference between the very basic I_{twist} and I_{rock} from our cylindrical model. These smaller differences may very well be overshadowed by other factors, such as the range of variation in shape among human torsos or even in the speed of articulation across individual signers. Thus, we adopt a simple model of the torso that can distinguish between two very different moments of inertia that are relevant to reactive effort in signing. These two moments of inertia are calculated according to the equations in 1.

(1) $I_{\text{twist}} = mr^2/2$
$I_{\text{rock}} = m(3r^2 + 4h^2)/12$

For a typical human torso, the torso is narrower than it is tall (Bottomley & Andrew 1978); that is, $2r < h$, so $r < h$. Since both measurements are positive, we thus have the inequality $0 < r < h$. Given this inequality, the two moments of inertia in 1 follow the inequality in 2, as proven in 3.

(2) $I_{\text{twist}} < I_{\text{rock}}$

(3)

$r < h$	given
$r^2 < h^2$	square both sides
$2r^2 < r^2 + h^2$	add r^2 to both sides
$6r^2 < 3r^2 + 3h^2$	multiply both sides by 3
$6r^2 < 3r^2 + 4h^2$	add h^2 to the right side
$mr^2/2 < m(3r^2 + 4h^2)/12$	multiply both sides by $m/12$
$I_{\text{twist}} < I_{\text{rock}}$	substitution with equations in 1

This inequality means that it takes less torque to cause the torso to twist than it does to cause the torso to rock. That is, the torso has less inherent resistance to twisting than it does to rocking, so manual articulations can more easily induce twisting.

Since induced torso movement is undesirable and therefore calls for reactive effort to resist it, we expect manual movements that more easily induce torso movement to be more disfavored. That is, the inequality in 2 can be extended to represent a scale of the expected relative frequency of the corresponding manual movements that induce twisting and rocking. So we predict that signs that induce twisting should be rarer than signs that induce rocking.

5.2. Twisting versus rocking in monoaxial signs. For monoaxial signs, there are four destabilizing movements. Of these, both +LR and −AT induce twisting, while +AT and −UD induce rocking (front-back and left-right, respectively). Thus, given the inequality in 2 and the relationship between moment of inertia and required torque to induce a movement, we expect that twisting movements (+LR and −AT) should collectively be underrepresented among destabilizing monoaxial signs, and rocking movements (+AT and −UD) should be overrepresented.

The destabilizing monoaxial signs in our data for LIS, SLSL, and ABSL are distributed between rocking movements (+AT and −UD) and twisting movements (−AT and +LR) as shown in Table 6. These distributions are also graphed proportionally in Figure 16, along with the expected proportion according to a uniform distribution in which each of the four types of destabilizing monoaxial signs is equally likely.

	LIS	SLSL	ABSL
ROCKING	29	6	4
TWISTING	6	4	0

TABLE 6. Distribution of destabilizing monoaxial signs by torso movement.

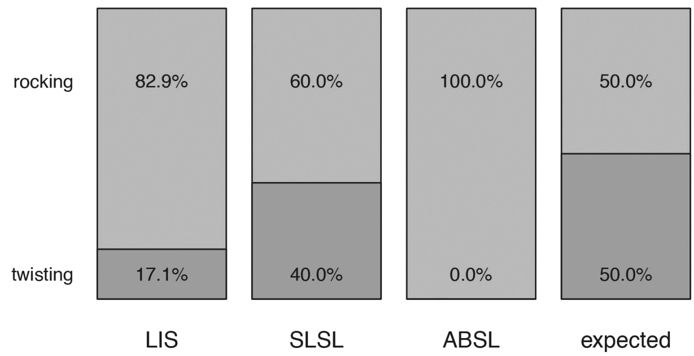

FIGURE 16. Proportions of destabilizing monoaxial signs by torso movement.

There is no significant difference between the three languages' overall distributions for destabilizing monoaxial signs ($p = 0.23$ for Fisher's exact test), and in all three languages, the rocking signs outnumber the twisting signs, though this is statistically significantly different from the expected uniform distribution only for LIS ($p < 0.01$ for Pearson's χ^2 test), not for SLSL or ABSL ($p = 0.75$ and $p = 0.12$, respectively, with simulated p-values using 100,000 replicates). However, the pattern for SLSL and especially ABSL is suggestive of the same pattern in LIS, in which rocking signs are overrepresented among destabilizing monoaxial signs and twisting signs are underrepresented.

The preference in LIS (and suggested preference in SLSL and ABSL) for rocking over twisting among destabilizing monoaxial signs is predicted by our proposal that languages tend to minimize reactive effort as part of an overall drive toward articulatory ease. Specifically, because of its lower moment of inertia, twisting is more easily induced than rocking is, so more reactive effort must be spent to resist it. Greater reactive effort is undesirable, so movements that induce twisting are more strongly dispreferred than movements that induce rocking.

5.3. TWISTING VERSUS ROCKING IN MULTIAXIAL SIGNS. For multiaxial signs, the comparison of twisting and rocking movements is much more complex, and an analysis is beyond the scope of this work. Consider just three issues.

First, the destabilizing effects of a cardinal movement can be mitigated when combined with another cardinal movement. Because a torque $\boldsymbol{\tau}$ is a cross product of two vectors, $\mathbf{r}$ and $\mathbf{F}$, its magnitude $\|\boldsymbol{\tau}\|$ depends not just on the magnitudes of $\mathbf{r}$ and $\mathbf{F}$, but also on the angle θ between them; the equation for this relationship is given in 4.

(4) $\|\boldsymbol{\tau}\| = \|\mathbf{r}\|\ \|\mathbf{F}\| \sin\theta$

For monoaxial signs, the manual movements are usually perpendicular to the axis of rotation, which means $\theta = 90°$, and since $\sin 90° = 1$, which is the maximum value of the sine function, a perpendicular torque has the maximum possible magnitude for a given distance and force. But for multiaxial signs, the movement is not perpendicular, which necessarily results in a lower magnitude for the resulting torque, down to 71% of the maximum magnitude when $\theta = 45°$ ($\sin 45° \approx 0.71$). Since the relative torque between movements is crucial to explaining why some may be more or less frequent than others (as in comparing the moments of inertia of twisting versus rocking), a full analysis of multiaxial signs would need a more precise measure of the relevant angles involved. Even if we had the equipment to make such measurements, we would still face the next two problems.

The second problem is that combining the same cardinal movements can induce different kinds of torso movement. For example, a multiaxial sign with +AT +UD +LR movement, such as the ASL sign PADDLE$_2$ 'operate a boat with a paddle' in Figure 17, induces twisting of the torso.

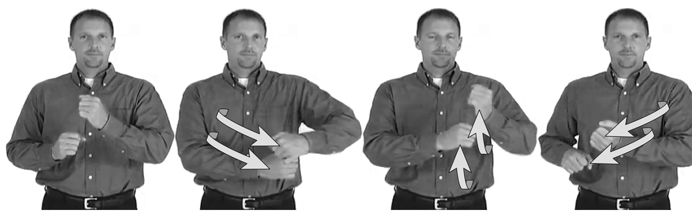

FIGURE 17. Twisting due to +AT +UD +LR movement in PADDLE$_2$ in ASL.

But the same three cardinal movements can be combined to induce rocking instead, as in the ASL sign WAVE in Figure 18.

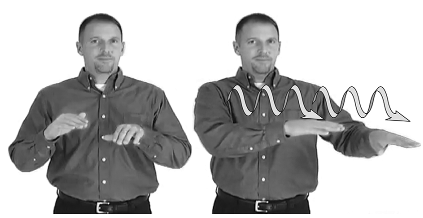

FIGURE 18. Rocking due to +AT +UD +LR movement in WAVE in ASL.

Thus, categorizing multiaxial signs solely by their component cardinal movements is not sufficient to uniquely identify which kind of torso movement they induce. Each sign must be individually evaluated, and for multiaxial signs, it can be difficult to identify which (if any) torso movement is induced, because of the problem discussed earlier concerning the decrease in a torque's magnitude in multiaxial signs.

Third, the number of destabilizing multiaxial signs in our data is too small to perform reliable statistical tests, so that very little of statistical significance could be said about twisting versus rocking in multiaxial signs for the data we have, even if we solved the first two problems. In light of these three problems, we do not attempt an analysis of twisting versus rocking in multiaxial signs.

5.4. SUMMARY. For destabilizing monoaxial signs in LIS, twisting movements as a group are underrepresented, while rocking movements as a group are overrepresented, a result that matches our predictions based on a drive to reduce reactive effort, since twisting is more easily induced than rocking and thus requires more reactive effort to resist. The same pattern is suggested by the monoaxial signs in SLSL and ABSL, but the pattern is not statistically significant. For multiaxial movements, we can make no generalizations given the complexity of the issue and the paucity of data.

6. THE POTENTIAL EFFECT OF CENTER OF MASS. When the manual articulators move, they can also change the signer's center of mass. For monoaxial signs, the three movements that move the hands in the same direction (+AT, +UD, and +LR) change the center of mass along the relevant axis, while the other three monoaxial movements (−AT, −UD, and −LR) keep the center of mass fixed because the manual movements balance each other out. Reactive effort is relevant to changes in the center of mass, because as the center of mass moves outward away from the UD-axis (i.e. toward the edge of or beyond the body's base of support) or upward along the UD-axis, the torso becomes easier to topple, so reactive effort may be required to prevent us from falling over.

The monoaxial signs in our data for LIS, SLSL, and ABSL are distributed by fixed or changing center of mass within each torso movement type (twisting, rocking, and stable) as shown in Table 7. These distributions are also graphed proportionally in Figure 19, along with the expected proportion according to a uniform distribution in which each of the two types of monoaxial signs for each torso movement type is equally likely.

			LIS	SLSL	ABSL
TWISTING	FIXED CM	−AT	5	4	0
TWISTING	CHANGING CM	+LR	1	0	0
ROCKING	FIXED CM	−UD	17	4	3
ROCKING	CHANGING CM	+AT	12	2	1
STABLE	FIXED CM	−LR	42	15	4
STABLE	CHANGING CM	+UD	30	10	7

TABLE 7. Distribution of monoaxial signs by change in center of mass for each torso movement type.

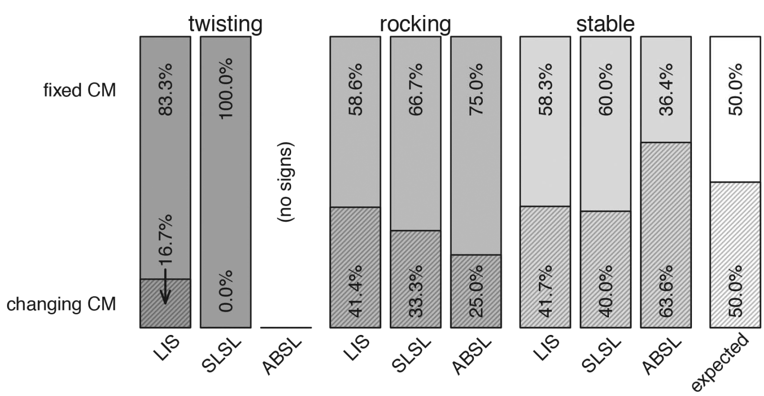

FIGURE 19. Proportions of monoaxial signs by change in center of mass for each torso movement type.

As always, if there are no other factors affecting the distribution, then we expect movements that induce the same type of torso movement to be evenly split between the two movements. For example, if there is no reason to prefer +LR or −AT movement over the other, then we expect twisting monoaxial signs to be evenly split between +LR and −AT movement. This is what we seem to find in our data: there is not enough evidence to conclude that any of a language's monoaxial signs are distributed nonuniformly between the two movement types for each type of torso movement ($p > 0.9$ for every case for Pearson's χ^2 test using simulated p-values with 100,000 replicates).

However, the lack of statistically significant nonuniformity may not be the result of an underlying uniform distribution. Instead, it may simply be the result of not having enough data to reliably observe whatever nonuniformity there may be. In every case except one (ABSL's stable signs), the proportion of signs that keep the center of mass fixed is greater, suggesting that there may be an overall preference to avoid changing the center of mass. In addition, this effect appears to be stronger for signs that destabilize the torso more: for each language where there is relevant data, the proportion of twisting signs that change the center of mass is smaller than the proportion of rocking signs that change the center of mass, which is smaller than the proportion of stable signs that change the center of mass. Again, these differences are not statistically significant for any of the three languages (p = 0.59 for LIS, p = 0.38 for SLSL, and p = 0.28 for ABSL, for Fisher's exact test), but the pattern is at the least suggestive, so further research is warranted to see what role center of mass might play in the larger concern for minimizing reactive effort.

7. Conclusion. We have shown that the distributions of monoaxial and multiaxial movements among signs in the lexicon with free two-handed single or retraced path movement (which have the greatest masses being moved) each seem to be the same for LIS, SLSL, and ABSL. Further, we have shown that manual movements that can induce incidental torso movement are underrepresented among these signs, while those that induce no incidental torso movement are overrepresented. We have also shown that manual movements that induce twisting (which is easier to induce because of a lower moment of inertia) are underrepresented among destabilizing monoaxial signs in LIS, while those that induce rocking are overrepresented; SLSL and ABSL exhibit the same pattern, but we do not have enough data for their pattern to be statistically significant. Finally, it seems that movement of the center of mass may also play a role in the shape of the lexicon.

Our findings are based on languages that are genetically unrelated to each other, and the patterns across these languages are not just qualitatively similar, but statistically indistinguishable in many cases, which is what we would expect if the drive to reduce reactive effort is intimately tied to human biology and not simply an optional pressure that languages may or may not succumb to. Though we have looked only at frequencies in the lexicon, we expect that these patterns may surface in other areas where articulatory ease can be relevant, such as conversational frequency, order of acquisition, disordered language, cooccurrence restrictions and alternations in compounds and other morphologically complex forms, and so forth. Language has long been known to exhibit a drive toward articulatory ease in these and other ways, but previous work on this issue has considered only the active effort of an articulation. We argue that a full analysis of articulatory effort must be expanded beyond active effort to also include reactive effort, which has not previously been considered in linguistics because of the field's historical focus on spoken languages, in which the moving masses are too small to induce readily noticeable incidental movement of other parts of the body. Since the manual articulators are massive enough to induce significant torso movement, sign languages present us with an opportunity to more readily observe and study the linguistic effects of reactive effort. Armed with this new awareness of reactive effort and its effects in sign languages, we can begin searching for its effects in spoken languages, too. Thus, not only does this work make a substantial contribution to the study of sign language phonetics (a relatively nascent field with far less literature than sign language syntax or even phonology; Crasborn 2012:4–5, Tyrone 2012:61), but it also opens up a new realm of research in phonetics as a whole, regardless of modality.

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